Situation Awareness in Airway Facilities: Replacement of Maintenance Control Centers with Operations Control Centers

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16. Abstract

The Federal Aviation Administration plans to consolidate the present Maintenance Control Centers (MCCs) into three Operations Control Centers (OCCs). This consolidation should increase efficiency and service by centralizing operations and by standardizing procedures. This document examines the likely effects of this consolidation on specialists' situation awareness (SA). Research psychologists from the National Airspace System Human Factors Branch (ACT-530) of the William J. Hughes Technical Center examined specialists' SA in the context of two basic plans. First, the Area-Specialist Plan maintains OCC specialists' responsibility for the same geographical areas they had in the MCC while continuing to monitor and control multiple technical systems. Second, the Technical-Specialist Plan would divide the responsibility of operations for one-third of the country between specialists in different technical areas. These two plans present very different and complex views of how best to implement OCCs. Each plan has advantages and disadvantages regarding SA. We discuss tradeoffs and examine a primary concern regarding SA and the transition from MCCs to OCCs.

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Executive Summary

Currently, there are 42 General National Airspace System Maintenance Control Centers (MCCs) responsible for the monitoring, control, and coordination of maintenance for Airway Facilities (AF) in the United States. The Federal Aviation Administration (FAA) is planning to consolidate these MCCs into three Operations Control Centers (OCCs). Consolidation of MCCs into OCCs should increase efficiency and service by centralizing operations in a few facilities and by standardizing the procedures used by those facilities.

Under the sponsorship of the Human Factors Division of the FAA (AAR-100), the National Airspace System Human Factors Branch (ACT-530) conducted a study to examine the likely effects of the transition from MCCs to OCCs on specialists' situation awareness (SA). This study involved reviewing the concept of SA as it relates to AF, looking at alternative measures of SA and evaluating their appropriateness for use in an AF environment, and hypothesizing alternative solutions for potential SA issues. This study lays the groundwork for more extensive research involving human-in-the-loop testing.

This study focused on specialists' SA in the context of two basic plans for the MCC to OCC consolidation. First, the Area-Specialist Plan proposes to maintain OCC specialists' responsibility for the same geographical areas they had in the MCC while continuing to monitor and control multiple technical systems. Very little would change under this plan except operations would be centralized and standardized. Essentially, the Area-Specialist Plan is in operation today. Second, the Technical-Specialist Plan proposes that each of the three OCCs would divide the responsibility of operations for one-third of the country between approximately 16 specialists in five or six different technical areas. The areas of responsibility in this plan would include Environmental, Communications/Telecommunications, NAVAIDS, Automation, Surveillance, Traffic (actually an Air Traffic position similar to a Traffic Management Unit), Help Desk, and Watch Lead. With exception of the Help Desk and Watch Lead positions, the specialists would be experts in their respective technical field.

There are tradeoffs to be considered between the Area-Specialist Plan and the Technical-Specialist Plan. The Area-Specialist Plan favors area-specific knowledge over technical knowledge while keeping SA in the purview of several individuals who must distribute their attention over various systems. The Area-Specialist Plan maintains current staffing and levels of workload while maintaining area-specific knowledge (e.g., potential effects of weather and terrain on facilities). The Technical-Specialist Plan allows specialists to focus attention on a particular system by favoring technical knowledge over area-specific knowledge and distributing SA across a larger team of individuals. The Technical-Specialist Plan may reduce the specialist-to-facility ratio and potentially increase workload.

These two alternatives present very different and complex views of how best to implement OCCs. Each has advantages and disadvantages regarding SA. We discuss the advantages and disadvantages and then hypothesize on potential solutions for optimizing SA under each plan.

1. Introduction

Under the sponsorship of the Human Factors Division of the FAA (AAR-100), the National Airspace System (NAS) Human Factors Branch (ACT-530) conducted a study to examine the likely effects of the transition from General NAS Maintenance Control Centers (MCCs) to Operations Control Centers (OCCs) on specialists' situation awareness (SA). This study involved reviewing the concept of SA as it relates to Airway Facilities (AF), looking at alternative measures of SA and evaluating their appropriateness for use in an AF environment, and hypothesizing on alternative solutions for potential SA issues. This study lays the groundwork for more extensive research involving human-in-the-loop testing.

1.1 Background

The concept of SA has been examined in many environments including fighter pilots (Carretta, Perry, & Ree, 1996; Endsely & Bolstad, 1994), Air Traffic Control Specialists (ATCS) (Durso, Truitt, Hackworth, Crutchfield, & Manning, 1998; Hopkin, 1994), automobile drivers (Gugerty, 1997), anesthesiologists (Gaba, Howard, & Small, 1995; Small, 1995), and chess players (Durso et al., 1995). Pilots, ATCSs, and others involved in dynamic environments have an intuitive sense of what it means to have good SA. For controllers, SA is simply "having the picture" or "not going down the tubes." More formal definitions of SA exist in the scientific literature (Durso & Gronlund, 1999; Endsley, 1988; Fracker, 1989; Mogford, 1994; Pew, 1994; Tolk & Keether, 1982), and each definition differs in regards to fine distinctions. Tolk and Keether provided perhaps one of the earliest definitions to appear in the literature. They defined SA as the ability to envision the current and future disposition of both friendly and hostile aircraft and surface threats. Endsley provided a more general definition of SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (p. 97). Despite the varied definitions of SA, all definitions tend to capture the same basic principle, that is, to have good SA is to be aware of the present state of events and to be able to predict and anticipate future events in a dynamic environment.

A lower and upper bound determines the potential of one's SA (Durso & Gronlund, 1999). An individual's SA is limited at the lower bound by the divided attention capacity of the individual. In other words, the amount of attention an individual gives to a task places a limit on SA. In addition, the individual must be able to acquire information from the environment and understand the meaning and implications of that information. To have adequate SA, one must have the prerequisite expertise and knowledge about the system of concern so that the correct information may be extracted from the environment and so that the implications of that information can be comprehended. The amount of attention given to a task determines how well information is acquired, updated, and understood. At the upper bound, the predictability of the dynamic system at hand determines potential SA. If the behavior of a system were completely random, then it would be impossible to predict and anticipate any future states of the system. Therefore, SA for the future situation would suffer in an unpredictable system. On the other hand, in a system that has some degree of predictability, one can use existing knowledge and expertise to foresee and anticipate the likely future state of the system.

1.2 Purpose

This document addresses the importance of SA for MCC specialists and which of their tasks are dependent on SA. It presents a review of methods used to assess SA and provides recommendations regarding which methods of SA assessment are best suited for use in the MCC/OCC environment. It also addresses how the replacement of MCCs with OCCs may affect the SA of OCC specialists. Hypothesizing about the effects on specialists' SA provides information to decision makers about the likely consequences for SA in OCCs and identifies potential avenues for future research. Finally, the authors propose alternative ways to resolve SA issues for OCCs.

1.3 Scope

This document addresses the relevance of SA to current MCCs and likely affects on SA in future OCCs. This document applies the principles of cognitive psychology to compare current MCC operations to a hypothetical plan that has been proposed for OCCs.

2. Areas in the MCC/OCC Relevant to SA

Currently, MCCs vary in equipment, layout, procedures, and software. Figures 1 through 3 illustrate the variations between three MCCs.

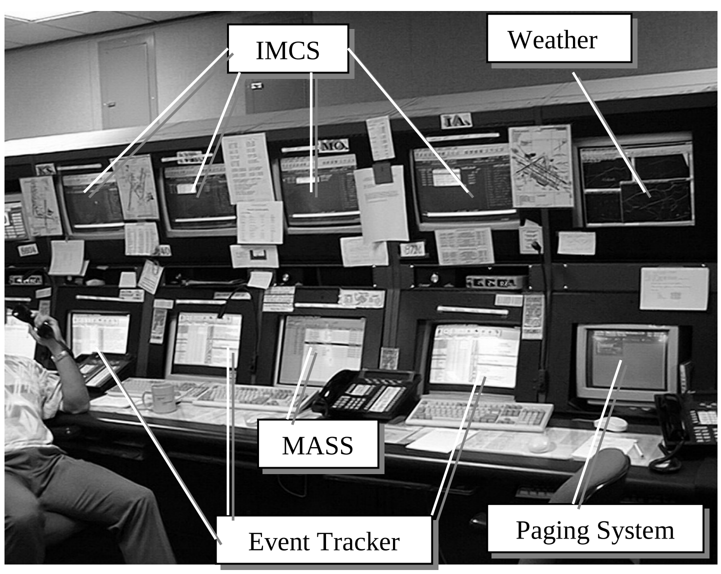

Figure 1. AF specialist workstation at Kansas City MCC.

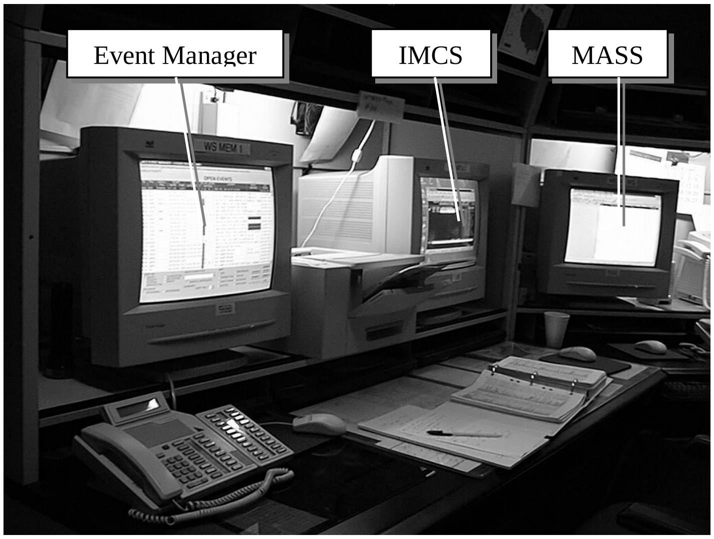

Figure 2. AF specialist workstation at Memphis MCC.

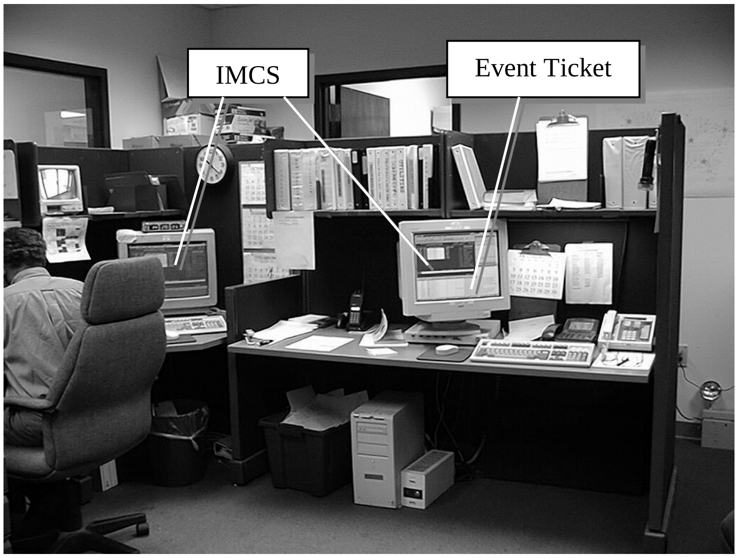

Figure 3. AF specialist workstation at Atlanta MCC.

Despite these variations, the jobs performed at fully functional MCCs are very homogenous. Systems Flow Inc. conducted a job task analysis for MCC specialists in 1994. The analysis identified 79 separate tasks that are performed by MCC specialists and the job requirements necessary to perform these tasks. Of these 79 tasks, the authors identified 7 tasks that are directly related to SA (shown in Table 1) and 7 tasks that are indirectly related to SA (shown in Table 2). The frequency of each task was estimated. High frequency tasks are performed more than five times per shift. Medium frequency tasks are performed two to five times per shift. Low frequency tasks are performed once or less per shift (Systems Flow Inc., Chapter 2, pg. 3).

The criticality of each task was also rated based on criteria defined in FAA-STD-028 (1985). Critical tasks (e.g., performing a flight check for accuracy on an instrument landing system) are those that must be performed correctly due to possible adverse impact on mission effectiveness or serious/fatal injury. Semi-critical tasks (e.g., correctly soldering a component in a piece of electronic equipment) are those that, if improperly performed, may cause some system degradation, equipment damage, personnel injury, and/or security degradation. The analysis conducted by Systems Flow Inc. rated all 14 of these tasks as being either critical or semi-critical.

Table 1. MCC Tasks Directly Related to Situation Awareness

Task	**Criticality**	**Frequency**
Check operational status by observing facility status monitor – RMM system	critical	high
Check environmental subsystems (e.g., fire, intrusion, engine generator) – RMM system	semi-critical	low
Check system status via modem – non-RMM system	critical	low
Check operational status – local system	critical	low
Monitor weather conditions and alert appropriate personnel as necessary	semi-critical	low
Initiate system control to prevent service interruption (e.g., start engine generator)	critical	low
Initiate system control to improve operation (e.g., switch between main and standby equipment)	semi-critical	low

Table 2. MCC Tasks Indirectly Related to Situation Awareness

Task	**Criticality**	**Frequency**
Acknowledge alarms – RMM system	semi-critical	high
Acknowledge alarms – local system	semi-critical	medium
Direct field maintenance technicians	critical	medium
Assist field technicians in trouble shooting	semi-critical	low
Prioritize restoration of system; determine criticality of system	critical	low
Respond to inquiries made by personnel in AF, AT, FSS, the military, contracted organizations, etc.	semi-critical	medium
Alert personnel of abnormal facility status; initiate callback as necessary	critical	low

Systems Flow Inc. also used The Job Element Rating Technique, which was developed by the Office of Personnel Management. This technique establishes job requirements for a variety of occupations and identifies and ranks 37 job requirements, also referred to as Knowledge, Skills, and Abilities (KSAs).

Each KSA was rated on four criteria:

a. Barely Acceptable Workers (What relative portion of barely acceptable workers is good in this element?)

b. Superior Workers (How important is this element in picking out the superior worker?)

c. Trouble Likely if Not Considered (How much trouble is likely if this element is ignored when choosing among applicants)

d. Practical to Expect (To what extent can we fill our openings if we demand this element of all applicants?)

Based on the criteria ratings, a Total Value was calculated to determine the extent to which each KSA should be considered during the selection of candidates for the MCC specialist occupation. The Total Value is calculated using the formula

$$\text{Total Value} = B + C + (B \times D) - A - D$$

where A = Score for Barely Acceptable Workers Criteria, B = Score for Superior Workers Criteria, C = Score for Trouble Likely if Not Considered Criteria, and D = Score for Practical to Expect Criteria. The formula returns the highest possible score for KSAs that are 1) more difficult in the job, 2) important to selecting superior workers, 3) likely to cause problems if ignored during the hiring process, and 4) practical to expect from the labor market. We identified six of the 37 KSAs as being relevant to SA. Table 3 shows the KSAs relevant to SA sorted by their Total Value Rank.

Table 3. Job Requirements Relevant to SA by Total Value Rank

Rank	Knowledge, Skill, and Ability
3	Ability to recognize, analyze, and deal with short term, real time equipment parameter trends
5	Ability to maintain a wide scope of awareness
21	Knowledge of extensive site-specific information within geographical area of concern (i.e., climate, terrain, roads, airport layouts)
28	In-depth technical knowledge of a specialty (i.e., Radar, NAVAIDS, Communications, Automation, Environmental)
30	Knowledge of weather forecasting terminology
34	Ability to interpret weather data

Based on the job task analysis conducted by Systems Flow Inc., there are two main areas in the MCC where SA is of particular relevance. The first area concerns monitoring the components of the NAS and the second area concerns monitoring maintenance activities and managing resources.

2.1 Monitoring the NAS

Monitoring the NAS involves being aware of components internal to the system and external components that impinge upon or use the system. MCC specialists must maintain awareness of internal components that comprise numerous technical systems. These systems are tracked in part by the Remote Monitoring and Maintenance System (RMMS) and the Interim Monitoring and Control System (IMCS). The RMMS includes the Maintenance Processing Subsystems (MPS) and associated software including the Maintenance Automation System Software (MASS)/Monitoring Control Function (MCF), the Maintenance Management System (MMS), and Simplified Automated Logging (SAL). The RMMS also includes the Remote Monitor Subsystems (RMS), the Maintenance Data Terminal (MDT), and the MCC itself. The RMMS allows MCC specialists to remotely monitor and control the status of selected NAS subsystems, log maintenance actions, and report service and facility interruptions and equipment failures. Awareness of the internal components of the systems allows the MCC specialist to gain an understanding of the overall status of the facility. External factors include the weather and air traffic (both current and predicted) for a given geographical area.

Monitoring internal factors of the NAS would seem to be an important part of the MCC specialists' duties. Studies were conducted based on observational and archival data from the Southern California Terminal Radar Approach Control (TRACON) MCC, Kansas City MCC, Salt Lake City MCC, and Chicago MCC. These studies showed that specialists only spend between 7% and 11% of their time actually looking at monitors that display information regarding the current state of internal and external factors affecting the NAS (FAA, 1997a; 1997b; 1997c; 1997d). Moreover, a study completed by the NAS Operations Program Operations Design Team (AOP ODT, 1999) found that at 6 of 21 MCCs visited, specialists did not perform any primary monitoring functions using the RMMS. Rather, they learn about outages by a telephone call from Air Traffic (AT) or AF field specialists. The AOP ODT report (AOP ODT, Appendix H) attributed the low level of primary monitoring via RMMS to lack of training regarding the use of the RMMS, lack of notification when a facility is connected to the MPS, failure of assignment of primary monitoring responsibilities for those facilities with RMMS capabilities, and lack of confidence in the ability of the RMMS to provide accurate information.

These studies reported that little (less than 8% of total time) or no monitoring of real-time information takes place at an MCC. However, studies conducted at MCCs that have the capability to remotely monitor AF sites may have underestimated the amount of time specialists actually engage in monitoring (FAA, 1997a; 1997b; 1997c; 1997d). These empirical studies estimated the amount and distribution of workload based on observational data. When a specialist was engaged in a particular task or looking at or using a particular system, an experimenter noted that activity. What the experimenters were not able to capture in their observations is how the specialists were dividing their attention among tasks. Although a specialist may have been engaged in a conversation with another person or engaged in a task other than active monitoring, it is likely that the specialist was still devoting some amount of attention to the aural warnings or highly visible changes on the monitors (K. Grayson, personal communication, August 26, 1999). Although monitoring of internal factors may have been more passive in nature (waiting for a signal to occur), it is likely that some degree of monitoring was occurring most of the time.

MCC specialists' monitoring of external factors is also relatively limited in that real-time information is not always available. Weather is the external factor that has the greatest impact on the current and future state of the NAS. However, most MCC specialists do not have access to real-time weather information. Weather information and forecasts are usually obtained by means of television broadcasts such as that given by The Weather Channel (K. Grayson, personal communication, August 26, 1999). Because The Weather Channel broadcasts information regarding the entire U. S. and occasionally other parts of the world, local weather information can be obtained only intermittently.

Given the limited RMMS capability (less than half of all sites) and the low level of primary monitoring by some MCC specialists, acquisition of real-time information may not contribute much to the SA of the specialist. Situation awareness may be more dependent upon the specialist's understanding of the current state of the system by means of delayed information that is obtained only after an alarm is noticed or an outage has significantly affected one or more NAS users. The fact that MCC specialists may not derive the majority of their SA from real-time display information implies that the task of the MCC specialist does not concern situations that are constantly changing and, therefore, is not highly dynamic.

2.2 Monitoring Maintenance Activities and Resources

Specialists must be aware of the current and likely future conditions of the NAS within an MCC. They must also have some awareness of the maintenance resources that are or will be available to keep the system functional. This awareness includes the availability of personnel, equipment, and spare parts used to maintain the facilities.

Specialists in an MCC maintain awareness of the current maintenance activities in progress by means of paper and pencil, the Event Ticket[1] software, the Event Manager[2]

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[1] Event Ticket is an event notification and tracking system. Authorized personnel can update it at any time during an event. Authorized personnel can tell at a glance who is involved with, the history of, and status of an event.

[2] Event Manager was designed to manage, track, and coordinate all events encountered in the day-to-day operation of an MCC or OCC. These events consist of facility or service interruptions, flight check coordination, facility commissioning/decommissioning, maintenance activities not requiring an interruption, maintenance of non federal facilities, tracking of telecommunication line problems, and problems with commercial power. The Event Manager is linked to the MMS.

software, or some other computer database. A study of workload distribution conducted at the Southern California TRACON MCC showed that specialists at that location spent 25% of their time using the Event Manager (FAA, 1997a). The Event Manager, more comprehensive than Event Ticket, lists maintenance activities that are currently in progress as well as the status of those activities. The Event Manager also provides a database to help the MCC specialist coordinate with the proper facilities that may be affected by an outage. Although available at all MCCs, the Event Manager is not widely used (R. Goff, personal communication, September 2, 1999) and most MCCs utilize Event Ticket or some other computer database program in the absence of any standard procedure. Currently, many (or most) MCC specialists do not have sufficient means to track the availability of maintenance resources such as field specialists or spare parts.

3. Replacing MCCs with OCCs

The goal of consolidating MCCs into OCCs is to centralize and standardize AF monitoring and maintenance activities in order to improve service to users (i.e., AT or AF field specialists) and customers (i.e., air carriers, the military, and the flying public) of the NAS. Such consolidation is meant to concentrate expertise in one location (an OCC) thereby increasing efficiency in responding to user and customer needs. There are two hypothetical plans in which the consolidation of MCCs into OCCs may occur.

The first plan proposes to have OCCs staffed by a team of specialists who are experts in a particular technical field or system (FAA, 1997e). Hereafter, this plan will be referred to as the "Technical-Specialist Plan." A second approach to replace MCCs would build upon current operations by having OCCs staffed by a team of specialists who are experts in a particular geographical area. This second plan would basically maintain the status quo and will be referred to hereafter as the "Area-Specialist Plan." This document will compare and evaluate both the Technical-Specialist Plan and the Area-Specialist Plan in terms of their likely effects on specialists' SA and their performance in OCCs.

3.1 The Technical-Specialist Plan

Under the Technical-Specialist Plan, replacement of MCCs with OCCs will result in two major changes to the task of the current MCC specialist. The first change involves an increase in the size of the geographical area that will concern the specialist. The second change concerns a shift in responsibility from one or two specialists who act as "generalists" (they handle a variety of aspects regarding monitoring and maintenance) to a larger team of specialists, each of whom will primarily concentrate on a single technical facet of the facilities that they monitor and maintain.

The tradeoff between area expertise and technical expertise is central to the implementation of OCCs. Specialists may not fully understand the implications of area-specific factors (e.g., weather) on all sites. However, their technical expertise would likely prevent many unplanned outages because they may be better able to recognize anomalous parameter readings. Technical expertise would allow specialists to capitalize on remote control capabilities and should lessen the time it takes to restore a facility to service. The tradeoff between area-specific knowledge and technical knowledge must be carefully considered.

3.1.1 Increased Geographical Area of Responsibility

Currently, 42 MCCs are responsible for monitoring and coordinating maintenance of the AF within the United States. Each MCC handles a relatively small geographical area. With the advent of OCCs, specialists will be responsible for a much larger geographical area. There will only be three OCCs with each covering an area roughly equivalent to one-third of the United States. Being responsible for a larger geographical area may potentially affect an OCC specialist's SA, at least initially.

The SA of an OCC specialist may suffer initially under the Technical-Specialist Plan because the area-specific knowledge gained in the MCC will apply only to a small portion of the geographical area in an OCC. In order to have sufficient SA, the specialist must have adequate area-specific knowledge of the environment and systems they are monitoring and maintaining. For example, the specialist must know about various environmental, terrain, and historical reliability factors that may impact the current and future status of any particular site. The specialist may be able to keep track of the current state of the systems within an area of responsibility by means of either real-time or delayed information. However, it may be difficult for the specialist to predict and anticipate the state of the systems in the future. Specialists moving into the OCC would lack the area-specific knowledge deemed important to anticipate and counteract potential outages in the geographically smaller MCCs (AOP ODT, 1999; K. Grayson, personal communication, August 26, 1999).

One proposed solution to compensate for the lack of area-specific knowledge is to establish and maintain databases containing the information and expertise possessed by current MCC specialists (AOP ODT, 1999). However, even if complete databases did exist, the information in the databases would not be readily accessible to the OCC specialist without a thorough (potentially time-consuming) search through the database. Even with an adequate database, specialists would have to know the proper types of queries to make or risk overlooking potentially relevant information. Having to search a database to be able to predict effects of factors such as weather does not only imply a limit on the OCC specialist's SA for future events but would increase workload and lengthen the time it took to respond to current or anticipated conditions. If specialists used a database to acquire knowledge during an unplanned outage caused by area-specific factors, they would simply be reacting to the outage rather than being proactive by using their own knowledge to prevent the outage. Databases would help specialists become more proactive only after they have had time to study and acquire the knowledge contained in the databases.

A second solution to the potential problem of specialists that lacked area-specific knowledge is to detail OCC specialists to MCC facilities prior to opening the OCCs (AOP ODT, 1999). This solution would give the OCC specialists some experience in other geographical areas; however, it may take a considerable amount of time before

OCC specialists would gain the level of knowledge and expertise needed to operate efficiently. A presentation by McMannis Associates (1997) states that MCC specialists require an average of 2 years of on-the-job training (OJT) in addition to formal training before they become proficient at their job. Although this OJT involves learning more than just area-specific information for each technical system, it is arguable that an OCC specialist would need at least 2 years to become proficient with all of the area-specific knowledge relevant to a particular technical system in an OCC. Detailing OCC specialists to various MCC locations in order to gain area-specific knowledge would also result in a burden on the staffing requirements for current MCCs. Furthermore, regardless of which plan is used to implement OCCs, training OCC specialists in some or all MCCs within an OCC geographical area would not address the future of OCCs when these highly trained specialists retired and took their knowledge with them.[3]

To eliminate staffing and retirement problems, a third solution to help OCC specialists gain area-specific knowledge would be to conduct OJT. By selecting specialists from a variety of MCCs to staff the OCCs, the theory is that area-specific knowledge from the MCCs could be shared among the OCC staff members. However, such OJT training requires that OCC specialists would have the time available to share their knowledge with each other. It is not apparent that much time would be available considering that about 16 to 20 OCC specialists would be responsible for the monitoring and maintenance activities for an entire one-third of the country. In other words, the issue of a potentially increased amount of workload may not allow much time for adequate OJT. At the very least, only a limited amount of time may be available for OJT and, therefore, it may take a considerable length of time before specialists possessed an adequate amount of area-specific knowledge, especially given the large number of sites they would have to learn.[4]

An alternative to OJT would be to have OCC specialists involved in some type of structured training program in addition to their regular working hours. While a structured training program would help specialists gain area-specific knowledge more quickly, taking time outside of normal duties may impose an increase on the staffing requirements.

Although lack of area-specific knowledge will eventually be remedied over time, in the interim, specialists are likely to have difficulty maintaining SA for events in which area-specific knowledge is needed to predict those events. The inability to predict and anticipate problems may result in more frequent unplanned outages than previously experienced in the MCCs.

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[3] As of September 30, 1993, a 10-year projection of AF work force demographics indicated that 39% of the employees serving in a technical/professional function would become eligible for retirement (Fu Associates, Ltd., 1994).

[4] Even if time was available for OJT, people vary in their ability to communicate, particularly when trying to impart implicit procedural knowledge. The speed and quality of OJT will vary depending on this ability.

A benefit of the Technical-Specialist Plan is that once an outage has occurred, specialists would have the required expertise to rectify the outage. This expertise would potentially allow a more rapid and efficient response to an outage as compared to those that act as generalists and only know a little about each system. Specialists who are technical experts would be able to remotely control many facilities. These specialists would also have more knowledge about the type of equipment they are monitoring and will be able to notice and correct anomalies in parameters before an outage occurs.

The inability to predict events based on area-specific knowledge may be offset by the specialists' ability to predict events based on technical knowledge. A lower level of NAS reliability and service may be experienced during the initial implementation of OCCs under the Technical-Specialist Plan only to the extent that the inability to predict outages via area-specific knowledge outweighs the ability to predict outages via technical knowledge. If the tradeoff favors area-specific knowledge, some decrement in NAS quality should be expected until OCC specialists are able to gain adequate area-specific knowledge to be able to predict situations that may result in outages. However, if the tradeoff favors technical knowledge, then little or no decrement in NAS quality should be expected as a result of better SA for both present and future events. In fact, it is possible that fewer unplanned outages would occur under the Technical-Specialist Plan because specialists would be more likely to notice and correct anomalous parameters that were being monitored due to their superior specialized technical knowledge.

3.1.2 Redistribution of Responsibilities

Currently, specialists in MCCs act as generalists in that they monitor numerous technical systems and coordinate and track the maintenance activities regarding those systems. In contrast, under the Technical-Specialist Plan, specialists in each of the OCCs would divide the responsibility of operations for one-third of the country between approximately 16 specialists in five or six different technical areas. The areas of responsibility in each OCC would include: Environmental, Communications/Telecommunications, Navigational Aids, Automation, Surveillance, Traffic (actually an AT position similar to a Traffic Management Unit), Help Desk, and Watch Lead. With the exception of the Help Desk and Watch Lead positions, the specialists would be experts in their respective technical field. Specialists currently in the MCCs are already experts in at least one technical field, so the impact of transitioning from a generalist to a specialist should be minimal if their technical skills have remained intact since previous training.

Specialists in OCCs may experience a positive benefit as a result of the redistribution of responsibilities from generalists to technical specialists. Technical specialists would be more able to notice and deal with anomalous parameter readings for systems they were monitoring. Because each specialist would be an expert in their technical field, they would have a greater knowledge base and set of experiences from which to draw upon to recognize patterns or conditions that may lead to unplanned outages. Additionally, there may be fewer unplanned outages because attention could be dedicated primarily to the monitoring of one particular technical system within the OCC under the Technical-Specialist Plan. Technical specialists may have better SA for both the present and future situation and would be better able to prevent unplanned outages. Once an outage did occur, the time it took to repair an outage should be shortened compared to an area specialist because the technical specialist would have a better idea of how the affected system operates.

The redistribution of responsibilities among fields of technical specialization in the OCC may improve specialists' SA for both present and future events regarding a single technical system, but specialists may have lower SA for other related systems. Rather than SA residing with one or two specialists as in an MCC, SA in an OCC will be distributed across a relatively large team of 16 to 20 specialists under the Technical-Specialist Plan. Although it is not likely that all members of the OCC team would need to share all available information, there will have to be a certain degree of shared, or group, SA. Therefore, it is important to know what information needs to be shared and with whom to share it. Team SA is important to the extent that one technical area is interrelated to other technical areas.

Specialists interviewed in support of this research effort indicated that one way to support team SA would be to have multiple common status boards that advise specialists about the other areas of responsibility. Other ACT-530 researchers are currently addressing the question of how to maintain team SA within an OCC that is organized under the Technical-Specialist Plan. Issues to be addressed should include what information may need to be displayed on common status boards and which specialists will need to communicate with each other most often. Understanding how the specialists communicate with each other in an OCC will impact the physical layout and seating arrangement of the OCC work area and will help maintain team SA. Steps must be taken to counteract the effect of redistributing SA from one or two specialists to a team of 16 to 20 specialists under the Technical-Specialist Plan. Such counteracting steps are necessary to the extent that the technical systems are interrelated.

A final possible effect of redistributing responsibilities under the Technical-Specialist Plan is that there is the potential for a higher level of workload per specialist. Fewer specialists in an OCC would be responsible for the same number of facilities that were previously monitored and maintained by numerous MCCs. Although specialists in the OCC would have a higher level of technical expertise and would be able to predict and deal more efficiently with outages that did not depend on area-specific knowledge, it is possible that this expertise would not be sufficient to offset the increase in workload resulting from a higher specialist-to-facility ratio under the Technical-Specialist Plan. A linear increase in specialist workload is likely to translate into exponential decreases in SA at some point (K. Grayson, personal communication, August 26, 1999). Therefore, if there is a higher facility-to-specialist ratio under the Technical-Specialist Plan, it should be ensured that the specialists' technical expertise would be able to offset any increases in workload.

In summary, the Technical-Specialist Plan for implementing OCCs chould result in specialists having better SA for both the present and future state of the particular technical system they are monitoring. However, there is a tradeoff. Specialists may have poor SA for future events that require area-specific knowledge to recognize because they will be lacking in such knowledge initially. The specialists' technical expertise and focused attention should allow them to be better able to recognize and counteract anomalous parameter readings that are being monitored to the extent that active monitoring of parameters is taking place. If the ability to predict outages rests more on technical knowledge than area-specific knowledge, fewer unplanned outages and an increased level of service may be experienced. Although OCC specialists may initially have trouble predicting and counteracting potential outages based on area-specific knowledge, once an outage did occur they would be able to remedy the outage in a more efficient manner because of their technical expertise and ability to use remote control capabilities.

There is no reason to believe at this time that the benefit of area-specific knowledge outweighs the benefit of technical expertise, but there are tradeoffs that would occur. It is an empirical question whether technical expertise would overcome a possible increase in workload due to: 1) Fewer OCC specialists would be responsible for the same number of facilities that were once handled by MCCs; and 2) the potential for an increase in the number of unplanned outages due to lack of area-specific knowledge. Finally, under the Technical-Specialist Plan, the redistribution of responsibilities requires that the issue of maintaining adequate group SA must be considered and dealt with in the design and implementation of OCCs.

3.2 The Area-Specialist Plan

The Area-Specialist Plan is an alternative to the Technical-Specialist Plan.. This plan of having each OCC specialist be responsible for only a small portion of the total area within an OCC was mentioned during previous interviews with subject matter experts (AOP ODT, 1999) and is essentially equivalent to maintaining current operations. Implementation of OCCs using the Area-Specialist Plan would result in one major change to the way MCCs are currently operated. This plan would consolidate former MCCs within the geographical boundary of an OCC into a single location. Such consolidation would allow the assignment of MCC specialists to future OCCs while still maintaining responsibility for the same approximate geographical location. Of course, there is the potential that some specialists will not want to relocate to the new OCC location.

The Area-Specialist Plan would maintain current levels of SA because the transition from MCCs to OCCs would be minimal in terms of losing area-specific knowledge. No decrements in specialists' SA would be expected because they would already possess the area-specific knowledge needed to be proactive in preventing unplanned outages due to area-specific factors. Therefore, the rate of unplanned outages should not increase with the implementation of OCCs under the Area-Specialist Plan. However, specialists under the Area-Specialist Plan would not be experts in all the systems they were monitoring. This lack of expertise would make them less likely to understand the implications of anomalous parameter values being monitored and they may not be able to fully utilize remote control capabilities. These specialists may have lower SA for both present and future events that depended on technical expertise as compared to specialists under the Technical-Specialist Plan.

The trade-off that occurs with the Area-Specialist Plan is that there will not be individuals assigned to a given geographical area of responsibility who are experts on each technical system. However, because there would be essentially the same number of specialists responsible for the facilities as in MCCs, numerous specialists would be consolidated in one location and it is likely that all areas of technical expertise would be represented on any given shift. The Area-Specialist Plan does not call for a substantial reduction in workforce so it may be more likely that workload remained manageable. Time and workload would need to be managed so that a specialist with needed technical expertise from one geographical area of responsibility could help another specialist who did not have the necessary technical expertise. Alternatively, technical experts, such as that provided by an operations support staff, could be available to handle the toughest technical problems. Staffing requirements should be optimized to ensure that specialists are not overworked (negatively affecting SA) or under-utilized (inducing complacency).

A potential drawback to the Area-Specialist Plan is that multiple monitoring and maintenance systems would have to be positioned in the OCC. Rather than having essentially one suite available to monitor each component of the NAS, a suite would be needed for each geographical area. One way to avoid a glut of monitoring equipment would be to consolidate the numerous complement of monitoring systems into a fewer number of monitoring systems. Such a consolidation of systems, although not an absolute necessity, would require additional design and research to ensure usability requirements. Consolidation of monitoring systems would result in a likely increase in SA compared to current MCCs because it would be easier for specialists to integrate and understand data that previously had to be obtained from disparate sources. Consolidation of monitoring subsystems is recommended regardless of whether the Area-Specialist Plan or the Technical-Specialist Plan is implemented. With consolidation of systems, SA for any one particular system in the Area-Specialist Plan may be lower than under the Technical-Specialist Plan because attention would have to be distributed across the various systems.

If deemed necessary, resources used to conduct additional design and research of consolidated monitoring systems under the Area-Specialist Plan would be traded-off with the same resources needed to conduct research in training programs and maintenance of group SA necessary under the alternative Technical-Specialist Plan. The Area-Specialist Plan would leave SA for all systems within a particular geographical area in the purview of a few specialists rather than distributed across numerous technical experts. The issue of maintaining group SA would be important only to the extent that specialists from various geographical areas needed to share information with one another.

In summary, the Area-Specialist Plan maintains the status quo while consolidating operations and standardizing procedures. This plan may require greater staffing requirements, but an increase in workload would not be expected. Specialists would retain area-specific knowledge and would be able to predict and counteract potential outages that depended on the use of area-specific knowledge. However, specialists would not have technical expertise on all systems they were monitoring and they may not be as likely to notice and counteract anomalous parameters. It would also take them longer to rectify an outage than if they possessed relevant technical expertise. SA for present and future events may be lower compared to the Technical-Specialist Plan to the extent that attention is widely distributed and SA relies on technical knowledge and recognition of anomalous patterns while monitoring. There is no reason to expect that unplanned outages would decrease under the Area-Specialist Plan, but there should not be any period in which unplanned outages would increase compared to current MCCs. Finally, specialists' SA would not be widely distributed across a number of team members under the Area-Specialist Plan and research regarding how to maintain group SA could be reduced or refocused to other areas.

4. Comparison and Testing of the Plans

The main issue highlighted by the previous discussion is the fact that there will be some tradeoffs regardless of whether the Area-Specialist Plan or the Technical-Specialist Plan is implemented. The Area-Specialist Plan currently being used in MCCs favors area-specific knowledge over technical knowledge while keeping SA in the purview of several individuals who must distribute their attention over a number of different systems. The Technical-Specialist Plan focuses attention on a particular system by favoring technical knowledge over area-specific knowledge and distributing SA across a larger team of individuals. These two alternatives present very different and complex views of how best to implement OCCs. It would be difficult to test all hypotheses in just a few experiments. Therefore, it is proposed that only the tradeoffs that appear to pose the greatest risk to the implementation and performance of future OCCs be examined by empirical methods.

5. Measurement of SA

Given the options that are available for the implementation of OCCs, it would be worthwhile to assess and compare specialists' SA for different implementation alternatives. Many different methodologies to measure SA currently exist including subjective and objective measures. Furthermore, participants can provide measures of SA either on-line or off-line. Measures previously used for the assessment of SA include psychophysiological measures such as eye movements (e.g., Moray & Rotenberg, 1989; Wierwille & Eggemeier, 1993), electroencephalograms and heart rate (e.g., Wilson, 1995), verbal protocol analysis (e.g., Ohnemus & Biers, 1993; Sullivan & Blackman, 1991), post-hoc techniques (e.g., Durso, Truitt et al., 1998; Rodgers, Mogford, & Mogford, 1995; Strauch, 1995), retrospective recall (e.g., Kibbe, 1988), supervisory and peer ratings (e.g., Bell & Waag 1995), subjective rating techniques (e.g., Vidulich & Hughes, 1991; Taylor, 1990), memory probes (e.g., Endsley, 1988), and on-line queries (e.g., Durso et al., 1995). For a current review of SA and methodologies used to assess SA, see Durso and Gronlund (1999).

5.1 Subjective Measures of SA

Subjective measures of SA such as the Situation Awareness Rating Technique (SART) and the SA-Subjective Workload Dominance (SA-SWORD) scale typically consist of Likert-type rating scales (Taylor, 1990; Vidulich & Hughes, 1991). These scales simply require participants to rate their level of SA for a previous time period. Participants using the SA-SWORD method rate their SA by making relative pair-wise comparisons for each experimental condition after a task or simulation has been completed. The SART measure obtains, in addition to SA ratings, a subjective rating of cognitive constructs related to SA such as attentional supply, attentional demand, and understanding.

Participants typically cannot provide subjective measures of SA on line because the measures require a certain amount of attention to complete. Making the rating tends to distract the participant from the primary task. Moreover, subjective measures of SA like SART and SA-SWORD tend to rely on memory for what happened during a preceding task or simulation. Such a reliance on memory will tend to bias the subjective rating of SA towards the most recent occurrences. This memory recall bias is known as the recency effect that is present with free-recall memory tasks (Murdock, 1962). Furthermore, there is some question as to whether or not participants, especially experts, can be fully aware of their own cognitive activity (Nisbett & Wilson, 1977). Because experts have a high level of procedural knowledge, it can be difficult for them to translate such knowledge into a declarative representation.

Although there are some inherent problems with subjective measures of SA, such measures are relevant in that they allow participants to express perceptions of their own SA. Participants who perceive that their SA was poor for a given task may be less motivated to perform that particular task in the future and negative consequences may result in terms of user acceptance and motivation. Therefore, while subjective measures of SA are limited in their use and subject to biases, such measures are important in gaining an overall understanding of any task or experimental manipulation.

5.2 Objective Measures of SA

A variety of objective measures of SA exist. The Situation Awareness Global Assessment Technique (SAGAT) developed by Endsley (1988) is one of the more cited methods for measuring SA. In general, the SAGAT measure operates by having the participant engage in a simulation. Then, at some point, the simulation is frozen and the experimenter removes all relevant information so that the participant no longer has access to it. The participant then answers a series of randomly selected questions obtained from a set of predetermined items. The accuracy of the participant's responses serves as the dependent measure of SA. Usually researchers score responses that fall within an acceptable range as "correct" because participants seldom recall verbatim information with a high degree of accuracy. For example, a researcher may score a response requiring altitude information in an AT task as being correct if the answer given is within 1000 ft of the verbatim answer. Exactly what degree of precision experimenters use in determining whether an answer was correct or not may greatly affect the validity and reliability of the SAGAT measure.

Although SAGAT is an objective measure of SA that has a high degree of face validity, there are some inherent drawbacks to this query technique. First, the SAGAT measure requires the experimenter to stop the simulation and administer the measure off-line. Some researchers have argued that interrupting the simulation changes the nature of the task at hand (e.g., Sarter & Woods, 1991). Interrupting the simulation is not only unrealistic, but it also may require the participant to spend some cognitive effort to regain an understanding of the situation after the simulation has been restarted. Therefore, SAGAT is very intrusive for most high fidelity simulations. Second, because SAGAT removes all relevant information before posing a query, the measure relies on the accuracy of the participant's memory as the dependent measure of SA. Remembering certain information may not be to the advantage of a participant, especially in certain tasks. In fact, remembering certain verbatim information is probably counterproductive in tasks that provide relevant information via primary displays. For example, in air traffic control, information such as an aircraft callsign, current and assigned altitude, heading, and speed are all shown on the plan view display. Memorizing exact displayed information would only use cognitive resources that the ATCS needs for other primary tasks such as maintaining aircraft separation. A study conducted by Gronlund, Ohrt, Dougherty, Perry, and Manning (in press) showed that ATCSs do not remember verbatim information. Rather, they tended to remember only the gist of the relationships between the elements under their control (e.g., aircraft A is higher than aircraft B).

Sarter and Woods (1991) and Durso et al. (1995) have proposed on-line measures of SA that overcome the problems of relying on a participant's memory and interruption of the simulation. Sarter and Woods have proposed an implicit performance measure that is directly related to SA. They suggest employing an error detection task in which experimenters measure the time it takes a participant to react to an error or anomaly in a simulated scenario. While this implicit performance measure of SA eliminates the problem of interrupting the simulation, experimenters must typically keep the frequency of error occurrences to a minimum in order to preserve the realism of the task. Using an error detection task realistically in an environment where errors do not occur very often results in a small number of data points to measure a participant's SA. Furthermore, it may not be obvious when a participant noticed an anomaly until the participant took some corrective action.

Durso et al. (1995) have developed an objective measure of SA that overcomes the problems of relying on memory, interruptions, and the frequency with which meaningful data can be collected. The Situation Present Assessment Method (SPAM) is an on-line query technique that allows the assessment of a participant's SA without interrupting the simulation or real-world activity. Initially developed with chess players, researchers have used SPAM successfully with ATCSs in simulations (Durso, Hackworth et al., 1998; Willems & Truitt, 1999), and automobile drivers in real driving situations (Chukwurah, Durso, & Truitt, 1999).

The SPAM measure of SA works by embedding queries within the task of concern. For example, ATCSs often receive calls over the landline communication system (like a telephone call). Rather than receiving a call from an adjacent sector or facility, controllers may intermittently receive a call from an experimenter asking about a relevant part of the task. Experimenters construct queries in consultation with an SME to ensure that the queries ask about information that is relevant to SA. Once the participant receives a query, the experimenter then measures the time it takes the participant to answer the query. Rather than simply recording whether the answer was correct or not, the experimenter can measure the time it took the participant to access the relevant information and respond. Additionally, SPAM queries involve information that is relevant either to a present or future situation. Response accuracy to the SPAM measure is usually quite high because all of the information needed to respond to a query is present and available to the participant at all times. Overall, SPAM allows for frequent on-line measurement of SA regarding both the present and future situation without disrupting the primary task.

5.3 Measurement of SA in AF

The best measures of SA for use in the AF environment are yet to be determined. Responses to the questions posed to the SMEs and the upcoming visits to operational MCCs will provide more insight about the appropriate measures. However, it is reasonable to expect that both subjective and objective measures of SA would be useful and appropriate in the AF environment even though real-time information may not be as important as in other, more dynamic tasks.

Subjective measures of SA will be useful in the AF environment because specialists will likely notice large changes in their SA that may be induced by certain conditions such as lack of area-specific knowledge. A simple way to assess SA would be to have the specialist respond to the question, "How aware are/were you of the present/future state of the system?" Each specialist could respond to the question by making a Likert scale rating. Depending on the level of taskload, specialists could make responses to the subjective measure of SA on-line at predetermined points during a simulation without much disruption.

Objective measures of SA could also be used to support the subjective ratings made by specialists. Researchers could employ an implicit measure of performance to assess how quickly specialists noticed an outage or how quickly specialists took the proper action to prevent or resolve an outage. Additionally, an on-line query method such as SPAM could be used to assess how aware specialists are of information that is relevant to the present state of the system. Researchers could also use the SPAM to assess how well specialists are able to predict what will happen in the near future. Specialists' ability to predict the future may be especially important because designers of the OCCs would like specialists to be more proactive and service oriented. The SPAM measure of SA could probably be implemented in a realistic way so as not to interrupt the simulation to any large extent. Future discussions with SMEs and visits to operational MCCs will help determine if the SPAM measure can be incorporated into the task of the MCC/OCC specialist in a realistic manner. It is possible that the SPAM dependent measure of reaction time may not be sensitive enough for use in the AF environment (i.e., variance may be too large). Because SA has never been examined in the AF environment, a pilot study is essential to determining the usefulness of various SA measures.

6. Conclusions and Recommendations

SA is relevant for the MCC specialists in that they must maintain an awareness of the current status of the NAS and be able to predict the future status of the NAS. Specialists maintain SA by using both area-specific and technical knowledge. However, the task of the MCC specialist is not very dynamic in nature because of the limited amount of monitoring that involves real-time information. Specialists in the MCC are able to anticipate the future status of the NAS in part because they possess a relatively high level of area-specific knowledge about the facilities of concern. This area-specific knowledge also helps them anticipate and cope with problems associated with maintenance and repair functions when dispatching field specialists. However, current MCC specialists often lack the technical expertise that is required to recognize anomalous parameter readings and repair a system once an unplanned outage has occurred. In addition to SA, effective problem solving and decision making are important cognitive processes for the MCC specialist.

OCC specialists under the currently used Area-Specialist Plan would remain responsible for numerous operations concerning a small geographical area within an overall OCC area. This plan does not focus technical expertise in a particular facet of operations within an OCC, but it does eliminate the need for additional training and immediate construction of databases while leaving area-specific knowledge intact. However, maintaining the status quo is advantageous for SA only to the extent that area-specific knowledge is important for specialists to be able to anticipate and counteract events that will impact the NAS before they occur. Specialists would probably have a lower level of SA for present and future events as compared to specialists in the Technical-Specialist Plan to the extent that SA relies on technical expertise.

Area specialists in current MCCs are not able to focus their attention on one particular system. In addition, the parameters of the systems being monitored do not provide the same depth of information and meaning to the specialist who has technical expertise. The Area-Specialist Plan should ensure that workload will not be excessive during the initial implementation of OCCs and eliminates, to some extent, the necessity to address issues regarding distributed group SA. Group SA will be important though to the extent that specialists from different geographical areas need to interact with one another. There is no reason to expect that unplanned outages would decrease under the Area-Specialist Plan, but there should not be any period of time in which unplanned outages would increase either.

The implementation of OCCs under the Technical-Specialist Plan will eliminate most of the area-specific knowledge currently possessed by MCC specialists. This is because specialists will be responsible for a much larger geographical area with which they are unfamiliar. Although area-specific knowledge may reside in a yet to be constructed database, such knowledge will not be readily available for use during an outage. Therefore, the database would not initially assist the specialist in being proactive. Databases would eventually help specialists become more proactive once they were able to gain experience with the databases and acquire the knowledge contained therein.

As a result of not having area-specific knowledge for facilities in such a large geographical area, OCC specialists will not be able to predict some future events without the help of some type of artificial intelligence (AI) mechanism or extensive training. Therefore, until OCC specialists gain area-specific knowledge or until some sort of AI mechanism is in place, OCC specialists will only be able to react to outages that have already occurred and impacted NAS users and customers due to area-specific factors such as weather or terrain. In other words, it is expected that OCC specialists may have very poor SA for future events that rely on area-specific knowledge to be detected.

The hypothesized problem of low SA in the Technical-Specialist Plan for future events requiring area-specific knowledge may be compounded by the fact that SA will have to be distributed among a team of specialists. The resulting issues of distributed team SA among specialists responsible for different technical facets of the NAS are only beginning to be addressed by other researchers. Workload may also increase under the Technical-Specialist Plan because it is expected that fewer specialists will be responsible for the same number of facilities.

On the other hand, the Technical-Specialist Plan may offset any increases in workload and/or number of unplanned outages because of the expertise that each specialist will possess. Workload may be offset by the fact that specialists will be technical experts in monitoring, solving, and rectifying unplanned outages. Specialists with expertise in the particular system they are monitoring should be better able to recognize and correct any anomalous parameter values before an outage occurs. In other words, technical experts should have better SA for the present and future events that are not dependent on area-specific knowledge. Once an outage did occur, specialists with technical expertise would be better able to handle the outage, thereby shortening the mean time to repair an outage. Furthermore, technical specialists could focus their attention primarily on one facet of the monitoring and maintenance responsibilities. Being able to focus on one particular system rather than distributing attention across many systems should also enhance the specialist's SA for the system being monitored.

Empirical investigations of the hypothesized effects should be conducted. Because of the complexity of each plan, a careful study of the effects with the greatest potential to impact the OCC should be given priority under time constraints. Results from these investigations can then be used to help further inform decision makers as to which plan would be most beneficial for SA and the implementation of OCCs.

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Acronyms

AF	Airway Facilities
AOP	National Airspace System Operations Program
AT	Air Traffic
ATCS	Air Traffic Control Specialist
FAA	Federal Aviation Administration
IMCS	Interim Monitoring and Control System
KSA	Knowledge, Skills, and Abilities
MASS	Maintenance Automation System Software
MCC	Maintenance Control Center
MCF	Monitoring Control Function
MDT	Maintenance Data Terminal
MMS	Maintenance Management System
MPS	Maintenance Processing Subsystems
NAS	National Airspace System
OCC	Operations Control Center
OJT	On-the-Job Training
RMS	Remote Monitoring Subsystem
RMMS	Remote Monitoring and Maintenance Center
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SAL	Simplified Automated Logging
SART	Situation Awareness Rating Technique
SME	Subject Matter Expert
SPAM	Situation Present Assessment Method
TRACON	Terminal Radar Approach Control